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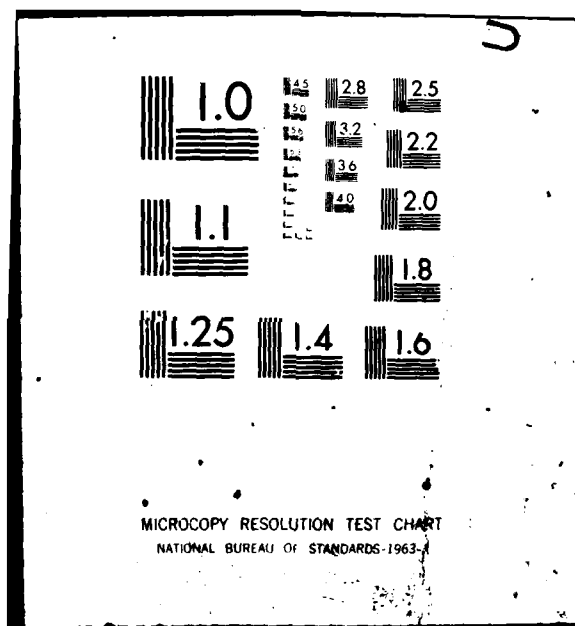
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STUDY OF ASPHALTIC CONCRETE PRODUCED IN  
DRYER DRUM MIXERS FOR AIRPORT PAVEMENTS

E. T. ROSHOLT



October 1976  
Final Report

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# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
<b>LENGTH</b>				
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
<b>AREA</b>				
in <sup>2</sup>	square inches	6.5	square centimeters	cm <sup>2</sup>
ft <sup>2</sup>	square feet	0.09	square meters	m <sup>2</sup>
yd <sup>2</sup>	square yards	0.8	square meters	m <sup>2</sup>
mi <sup>2</sup>	square miles	2.6	square kilometers	km <sup>2</sup>
	acres	0.4	hectares	ha
<b>MASS (weight)</b>				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
<b>VOLUME</b>				
teaspoon	teaspoons	5	milliliters	ml
Tablespoon	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cup	0.24	liters	l
pt	pint	0.47	liters	l
qt	quart	0.95	liters	l
gal	gallons	3.8	liters	l
ft <sup>3</sup>	cubic feet	0.03	cubic meters	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.76	cubic meters	m <sup>3</sup>
<b>TEMPERATURE (exact)</b>				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

\*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13.10.286.

## Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
<b>LENGTH</b>				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
<b>AREA</b>				
cm <sup>2</sup>	square centimeters	0.16	square inches	in <sup>2</sup>
m <sup>2</sup>	square meters	1.2	square yards	yd <sup>2</sup>
km <sup>2</sup>	square kilometers	0.4	square miles	mi <sup>2</sup>
ha	hectares (10,000 m <sup>2</sup> )	2.5	acres	ac
<b>MASS (weight)</b>				
g	grams	0.005	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	st
<b>VOLUME</b>				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m <sup>3</sup>	cubic meters	35	cubic feet	ft <sup>3</sup>
m <sup>3</sup>	cubic meters	1.3	cubic yards	yd <sup>3</sup>
<b>TEMPERATURE (exact)</b>				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



## PREFACE

This study was supported by the Systems Research and Development Service of the Federal Aviation Administration. This is a final report presenting the characteristics of three types of drum mixers; Shearer parallel flow, McConnaughay turbulent mass, and RMI Thermo-Matic system. This report is intended to acquaint engineers and field inspectors with some of the characteristics of the dryer drum mixers and the asphaltic concrete mixes produced by these mixers. This report is not an endorsement of the product.

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PART I  
SHEARER PARALLEL FLOW PROCESS

INTRODUCTION

This study of the Shearer parallel flow process\* was conducted on the results of two mixers, one large and one small. A 500 ton (454Mg) per hour mixer was used for the construction of the runway, taxiways, and aprons at the Grand Canyon Airport, and a 100 ton (91 Mg) per hour model was used for construction of the taxiway extension, stub taxiways, and warm-up area at the Prescott Airport. Both airports are in the State of Arizona. Federal aid is under the supervision of the Los Angeles District Office in the Western Region of the Federal Aviation Administration.

The Nome, Alaska, airport pavement was also constructed with the Boeing Shearer 600 ton (544 Mg) per hour parallel flow plant. A report prepared by the Alaskan Region on this project is included as Appendix A.

\* See Photographs A thru D.

## PURPOSE

The purpose of this study was to collect information on bituminous mixes produced by the Shearer drum mix process for use on airport pavement projects.

A study was undertaken to determine the ability of this method to meet FAA standards for bituminous concrete. Changes to FAA Standard Specifications to permit use of dryer drum mixed asphalt concrete are proposed.

## SCOPE OF THE STUDY

The scope of the study included the following:

- A. The effectiveness of air quality control as to the amount and character of the stack emissions of the mixer at various production rates.
- B. Correlation of the Marshal method of design, using the temperature specified for the viscosity of the asphalt used with a modified Marshall procedure using the lower temperatures anticipated by the use of the Shearer process.
- C. Evaluate the rolling techniques versus density requirements and the adequacy of the present special provisions concerning the minimum density requirements with the product of the drum mixer.
- D. Determine the effect of direct fire on bituminous mixtures heated to 240°F (116°C), 260°F (127°C), 280°F (138°C), and 300°F (149°C), measured by the rolling thin film oven test, versus rehological analysis of the extracted bituminous material mixed in the Shearer process drum mixer.
- E. Determine the reliability of the Boeing Manufactured Shearer drum mixer equipment and ascertain if it can consistently produce a sufficient quantity of satisfactorily mixed asphaltic concrete to meet the production demands for heavy aircraft pavement designs, within a reasonable period of construction time.
- F. Determine the deviation from the mean of the "job-mix-formula" of the product from the Shearer parallel flow process drum mixer.
- G. Determine the testing laboratory deviation of final test results performed by various laboratories and technicians.
- H. Determine the methods and accuracy of the calibration of the plant together with a study of the ease of transition for the paving plant operator from standard stackup plants to the Boeing drum mixer.
- I. Determine the tolerances required for temperature control to accomplish a uniform sequence of rolling procedures.
- J. Recommended changes to FAA standards.

## PART I "A" ENVIRONMENTAL EFFECT OF SHEARER PROCESS DRUM MIXER

Stack emission control is one of the side benefits of the Shearer process mixing plant. The mixture from the drum mixer contains a higher moisture content than that from a standard dryer used with stackup plants. This higher moisture content combined with the addition of the asphalt cement during the heating and mixing cycle results in a low emission of dust particles from the exhaust stack. Additional water is sprayed into the exhaust gases with high pressure fog nozzles resulting in a stack emission primarily of steam.

Photographs were taken each hour of production for the purpose of evaluating the air contamination caused by the drum mixer only. It was noticed that less air contamination occurs from the mixer than from the loaders or from dust stirred up by gusts of wind around the stockpile area. Occasionally the stack emission carries more dust and/or smoke due to malfunctions of the water sprays or a changed burner output due to a change in aggregate moisture. When this occurs, the air pollution from the stack is carried a considerable distance while the exhaust of the loaders and dust stirred up around the stockpile is intermittent and dissipates locally.

High temperatures and/or high production rates sometimes alter the asphalt content. The results of asphalt content tests vary more at the high burner output and may be due to some of the burner oil not being ignited, resulting in dissolving some asphalt by the burner fuel and the mixture expelled through the exhaust stack.

#### PART I "B" CORRELATION OF THE MARSHALL DESIGN

This study of the Marshall method of design using the temperature specified for the viscosity of the asphalt used, and a modified Marshall<sup>1</sup> procedure using lower temperatures anticipated by the use of the Shearer process indicates a good correlation exists between the maximum densities obtained by the regular Marshall and the modified Marshall. The mix design should follow the same procedures as presently used for a standard stackup plant. Differences between the design mixture and the production mixture for the Shearer plant appear to be approximately the same as the differences for a stackup plant.

#### PART I "C" EFFECT OF DRUM MIXER ON DENSITY

The preliminary evaluation of the rolling techniques versus density requirements and the adequacy of the present special provisions concerning the minimum density indicated requirements for use of the drum mixer should not be changed from the present requirement for standard stackup plants. The results indicate that 98% of Marshall maximum density can be obtained under present FAA Specifications.

There are several items that the inspector should be aware of that are different from the mixture from a standard plant. They are as follows:

- a. During the initial rolling procedure the mixture may "puff up" immediately behind the screed and/or breakdown roller. This is caused by a higher than normal moisture content in the drum mixed asphaltic concrete. The moisture

<sup>1</sup> The modification in this case was testing specimens from mixtures produced by the drum mixer at temperatures varying from 220° to 240°.

soon dissipates, and normal rolling procedures can continue in about 5 minutes depending on temperature of the air, wind velocity, sun or cloud cover.

b. The mixture may occasionally seem to be highly over asphalted and become so fluid that it "runs" on the production belt and slumps in the bed of the truck. This condition is a result of a higher moisture content in the mixture and a high mixing temperature. This condition usually occurs at start up and arises from a rain shower on the stockpiles, condensation in the drum in the early morning, or when the dew point causes a damp condition in the aggregate. This high percent of moisture combined with a higher start-up mixing temperature provides an excess of lubrication resulting in a fluid condition. The inspector would assume the mixture to be over asphalted; however, that is not the case. The mixture will quickly "set" and lay down placement and rolling should be accomplished the same as a standard mixture. The additional lubrication assists in the compaction procedure. Tabulated test results indicate an average density in excess of 98% was obtained.

#### PART I "D" EFFECT OF DIRECT FIRE ON BITUMINOUS MIXTURES

The effect of direct fire on bituminous mixtures heated to 240°F (116°C), 260°F (127°C), 280°F (138°C), and 300°F (149°C) measured by the rolling thin film oven test (see Appendix B) versus rheological analysis of the extracted bituminous material from the Shearer process drum mixer indicates less aging of the asphalt occurs from the mixing in a Shearer process drum mixer.

Comparison studies of the Shearer process mixer versus standard stackup plants were conducted by Robert Dunning, PE, using the rolling thin film oven test as equal to the pugmill action of a stackup plant. The penetration of the aged residue indicates that mixing in the drum mixer has less damaging effect on the asphalt than the pugmill type even at mixing temperatures as high as 300°F (149°C) and probably higher.

It is recommended that the mixture be heated to a temperature between 240°F (116°C) and 260°F (127°C) to meet all design criteria (See Appendix B).

#### PART I "E" QUANTITATIVE RELIABILITY OF SHEARER PROCESS MIXER

The ability of the Shearer process drum mixer, to consistently produce a sufficient quantity of satisfactorily mixed asphaltic concrete meeting the production demands for heavy aircraft pavement designs, within a reasonable period of construction time, appears to be entirely satisfactory. The results indicate the reliability of the drum mixer is greater than the paving equipment used on this project (Cedar Rapids Pavers, used and new, and a used model Barber Greene). The ability of the drum mixer to consistently produce a quantity of 500 tons (454 Mg) per hour of asphaltic concrete is above expectations. The down time of the paving operation during construction that can be contributed to the drum mixer is less than 1% of the total down time of the paving operation.

#### PART I "F" QUALITATIVE ANALYSIS OF MIXTURE

The test results from the field control laboratory indicate that the deviation of the production mixture from the "target" job mix formula is

approximately the same as the deviation of the test results between the other four testing laboratories. The job mix formula gradations were not changed, however, the asphalt content was increased for paving lanes near the outside edges.

The occasional problems initially experienced with variations in the speed of the cold aggregate feeders have been corrected. Recent statistical testing procedures show that the test results of the mixture will stay within the specified tolerances 100% of the time when sampled on a random basis and the results averaged for each five sample lot. (The lot size was established at 2500 tons).

#### PART I "G" LABORATORY DEVIATION OF EXTRACTION TEST RESULTS

The testing laboratory deviation of final results of extraction tests performed by four testing laboratories plus the field control laboratory indicate the laboratory testing deviation is as great or greater than the plant deviation. The results of this portion of the study indicate that some revision may be necessary in the evaluation of test results. Large hot mix samples were taken, and each laboratory meticulously split the sample and passed the balance on to the next laboratory. In that way each laboratory had the responsibility of testing a portion of each sample. It may be required that a combination of the results of cold feed samples and hot mix samples be used to evaluate the gradation of the production material. Extraction tests of 1500 grams of mixture may show a trend, but to use the results for plant control and for acceptance of the mixture as presently required by FAA is not recommended for either the drum mixer or the standard stackup plants. A variable tolerance is suggested with a wider tolerance for fewer tests and a tighter tolerance for acceptance as the number of tests are increased. The average of five tests for a 2500 ton



lot appears to minimize the variation caused by the testing procedure.

#### PART I "H" PLANT CALIBRATION AND EASE OF TRANSITION

The calibration of the Shearer Process drum mixer is simple and accurate. The dry gradation of the aggregate in each bin must be established and theoretical mix proportions set up. Once this is ready, the plant operator can set each feeder dial on the required proportion. The plant operator may increase or decrease the plant production by a turn of the master dial which controls all components in the same proportion as the initial calibration.

The operation transition from a standard stackup plant to a drum mixer is relatively easy for a qualified operator. The maintenance and repair of the electronic control system are also comparable to standard plants. Future studies of new developments in the feed systems may indicate greater reliability of the equipment than that required by the present specifications.

#### PART I "I" EFFECT ON ROLLING PROCEDURES

The tolerances required for temperature to accomplish a uniform sequence of rolling procedure are the same as presently used for conventional mixes to establish the proper or best sequence of rolling operations. The technicians must become acquainted with unusual appearances

and in some cases vary his procedures to meet the conditions of the mixture; however, the same procedure is necessary with mixtures from a standard stackup plant.

The rolling sequence is determined by using an outside lane of the runway, taxiway or apron for a test area. The temperature of the mix at the time of "breakdown" is varied together with changing the rollers for breakdown and finishing. Nuclear readings are taken between each pass and plotted as lbs./c.f. (kg/m<sup>3</sup>). The sequence giving the highest density without overrolling should be used.

#### PART I "J" RECOMMENDED CHANGES TO FAA STANDARDS

The recommended changes to the FAA standards for Item P-401 Bituminous Surface Course are contained in Appendix C.

#### FIELD APPLICATION NOTE

It was noticed in field application that as the mixture temperature increased, the mixture would become very fluid depending on the amount of moisture in the aggregate causing a "runback" on the hot production belt. The hot mixture with more than 2% moisture also puffed up behind the screed of the paving machine and/or the breakdown roller and required holding back on the rolling procedure a few minutes to obtain maximum density. The end product did not seem to vary because of the higher temperatures, and no particular value could be realized except at the start on cold mornings. The higher temperatures at that particular time seemed to result in a better cold joint. This may have been due to heating up the truck beds and the paver and a little less labor required to build a good joint. The higher temperatures would also release asphalt cement

and fines which had previously built up in the exhaust stack and result in a slightly finer mixture with a higher asphalt content for the first few loads. Results of tests conducted on the mixture did not show it to be out of the specification tolerance probably due to the "funneling" effect of the discharge of the mix from the surge bin.

#### NOME, ALASKA PROJECT

As reported in Appendix A, paving of the Nome, Alaska project was accomplished in 1973 with a Shearer drum mixer processing the asphaltic concrete. In September, 1976 the Alaskan Region of FAA reported that the runway pavement had transverse thermal cracks approximately 200 feet apart. The width of the cracks ranged from approximately 1/8 inch to 3/4 inch. Only a few cracks were 3/4 inch wide. The cracks were observed to extend through the gravel shoulders. Beside the cracks, the pavement was free of defects and in good condition. No real concern about the cracks was expressed by the Alaskan Region.

#### CONCLUSIONS AND RECOMMENDATIONS

See page 21 for conclusions and recommendations included with those for the McConnaughay process.

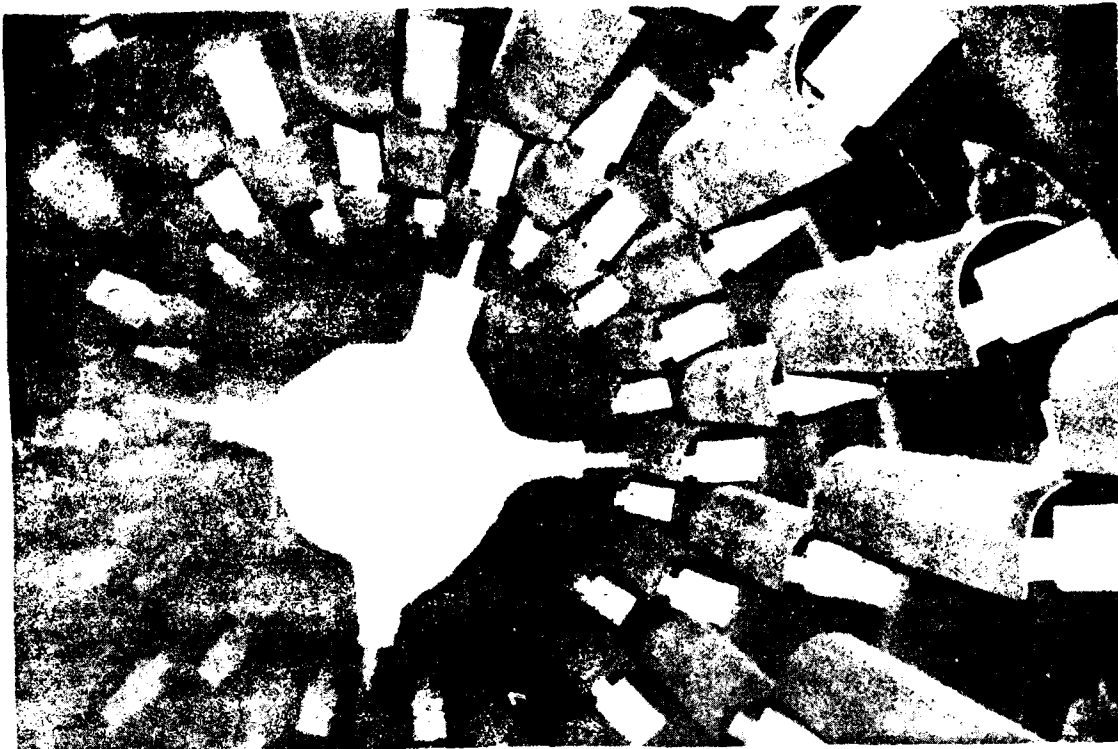


Fig. 1. View of the fly plate. Very little visible structure is present in the fly plate.



Fig. 2. View of the fly plate. Approximately 10% of the fly plate is visible.



Figure 1. - Spread layout of the Shearer Process drive system.

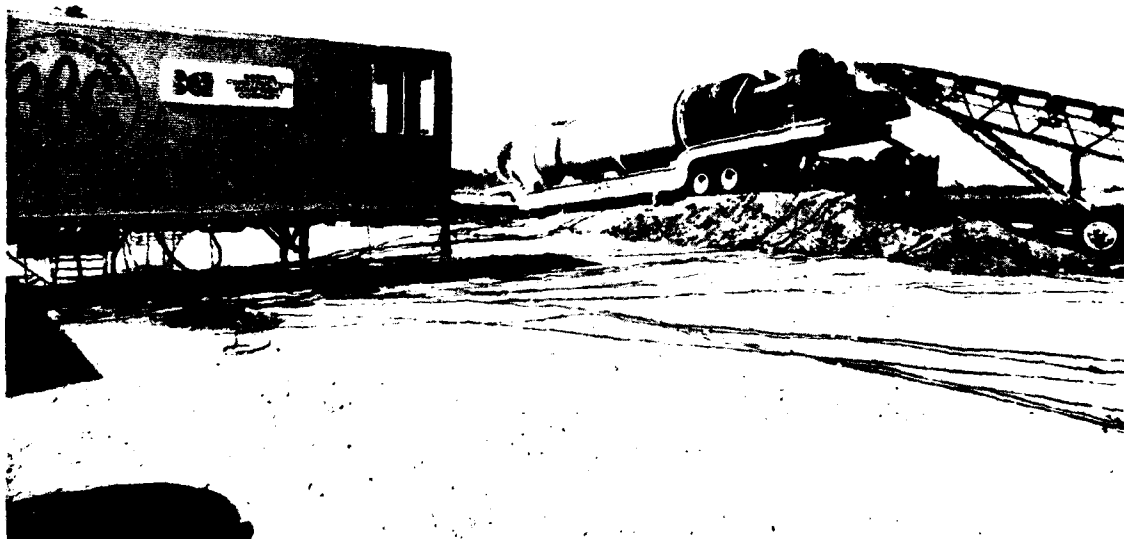


Figure 2. - Control cables plugged into the control var of Shearer drive system. No electronic problems were observed due to the cable failure in the system.

## PART II

### McCONNAUGHAY TURBULENT MASS PROCESS

#### INTRODUCTION

Four drum mixers manufactured under license by the McConnaughay Company were inspected, they are as follows:

"DUAL-ZONE" THERMODRUM	Manufactured by Barber Green-Aurora, IL
"TMM" (turbulent mass mixer)	Manufactured by Cedarapids-Cedar Rapids, IA*
"TURBULENT MASS PLANT"	Manufactured by CMI-Oklahoma City, OK**
"TURB-MIX PLANT"	Manufactured by Standard Steel, Los Angeles, CA

This study of the McConnaughay turbulent mass process was conducted on the test results of the Cedarapids "TMM" 600 ton (544Mg) per hour drum mixer.

The lack of airport construction due to the curtailment of the Airport Development Aid Program by FAA made it impossible to study this process on airport construction.

Therefore an Arizona Department of Transportation (ADOT) highway project with quality control procedures and design methods compatible with the FAA procedure was substituted. The project chosen was on US Highway #89 at Cameron, Arizona. The mix design gradation was on the coarse side of the FAA specification for airport surface course P-401 (Column A). The Marshall method of design (ASTM-1559) was used by the Arizona Department of Transportation for the mix design and job mix formula. The design mix was not as dense as FAA requires nor did it contain as much asphalt cement. The design criteria for effective voids was 4% to 6% while FAA design is for 3% to 5% voids. The design criteria for percent voids filled were 65% to 70% while FAA criteria were 70% to 80%. However during

\* See Photograph E.

\*\* See Photograph F.

construction the percent total voids was on the low side and fell within the FAA criteria and the percent voids filled with asphalt was on the high side and fell within the FAA criteria. The project covered production of 68,558 tons (62,159 Mg) of asphaltic concrete.

## PURPOSE

The purpose of this part of the study was to evaluate the suitability of bituminous mixes produced by the McConnaughay turbulent mass drum mix process for use on airport pavement projects. The ability of this process to meet FAA standards was determined and recommended changes to FAA standards to permit use of the McConnaughay turbulent mass process drum mixed asphaltic concrete are included.



## SCOPE OF THE STUDY

The scope of the study included the following:

- A. The effectiveness of air quality control as to the amount and character of the stack emissions of the mixer at various production rates.
- B. Correlation of the Marshall method of design, using the temperature specified for the viscosity of the asphalt used with a modified Marshall procedure using the lower temperatures anticipated by the use of the McConnaughay turbulent mass drum mixer.
- C. Evaluate the rolling techniques versus density requirements and the adequacy of the present special provisions concerning the minimum density requirements with the product of the drum mixer.
- D. Determine the effect of direct fire on bituminous mixtures heated to 240°F (116°C), 260°F (127°C), 280°F (138°C), and 300°F (149°C), measured by the rolling thin film oven test, versus rheological analysis of the extracted bituminous material mixed in the McConnaughay turbulent mass drum mixer.
- E. Determine the reliability of the McConnaughay turbulent mass drum mixer equipment and ascertain if it can consistently produce a sufficient quantity of satisfactorily mixed asphaltic concrete to meet the production demands for heavy aircraft pavement designs, within a reasonable period of construction time.
- F. Determine the deviation from the mean of the "job mix formula" of the product from the McConnaughay turbulent mass.
- G. Determine the testing laboratory deviation of final test results performed by various laboratories and technicians.
- H. Determine the methods and accuracy of the calibration of the plant together with a study of the ease of transition for the paving plant operator from standard stackup plants to the McConnaughay turbulent mass.
- I. Determine the tolerances required for temperature control to accomplish a uniform sequence of rolling procedures.
- J. Recommended changes to FAA standards.

## PART II "A" ENVIRONMENTAL EFFECT OF McCONNAUGHAY SYSTEM

Stack emission control of the McConnaughay Turbulent Mass Mixer (TMM) plant results in air quality similar to that found in Part I for the Shearer Parallel flow plant. All four of the McConnaughay TMM plants are similar in design to the Shearer parallel flow plant. The lifters inside the Cedarapids drum are however quite different in that the lifters in the heating end of the drum have a slot between the drum and the lifter that permits the fine material to slide back while the coarse aggregate is carried up and drops directly into the burner flame. The coarse aggregate therefore absorbs heat from the hottest part of the unit without blasting the fine particles to the rear of the drum.

## PART II "B" CORRELATION OF THE MARSHALL DESIGN

This study of the Marshall method of design using the temperature specified for the viscosity of the asphalt used, and a modified Marshall procedure using lower temperatures anticipated by the use of the McConnaughay process is similar and equal to that found in part 1.

## PART II "C" EFFECT OF DRUM MIXER ON DENSITY

The evaluation of the rolling techniques versus density requirements and the adequacy of the present special provisions concerning the minimum density indicate requirements for use of the drum mixers should not be changed from the

present requirement for standard stackup plants. The results indicate that the ADOT specification for a minimum density of 92% can be obtained.

#### PART II "D" EFFECT OF DIRECT FIRE ON BITUMINOUS MIXTURES

The similarity between Shearer parallel flow process and the McConnaughay Turbulent Mass system being practically the same would make this test redundant. Therefore, the analysis by Robert Dunning of the Shearer process will suffice for this part.

#### PART II "E" QUANTITATIVE RELIABILITY OF McCONNAUGHAY TURBULENT MASS MIXER

The ability of the McConnaughay process drum mixer to produce a sufficient quantity of satisfactorily mixed asphaltic concrete meeting the production demands for heavy aircraft pavement designs, within a reasonable period of construction time, is satisfactory. The ability of the Cedarapids drum mixer to consistently produce a quantity of over 600 tons (544 Mg) per hour of asphaltic concrete is remarkable. The daily production at times reached almost 6000 tons (5440 Mg) per day during this project. The down time of the paving operation during construction that can be contributed to the drum mixer is practically zero.

#### PART II "F" QUALITATIVE ANALYSIS OF MIXTURE

The test results indicate that the deviation from the "target" job mix formula was well within the ADOT expectancy. The results of statistical testing procedures show that the test results of the mixture will stay within the specified tolerances 100% of the time when sampled on a random basis and results averaged for each five sample lot. (The lot size was established at 2500 tons.)

## PART II "G" LABORATORY DEVIATION OF TEST RESULTS

This part of the drum mixer study was not performed. All test results were performed by two laboratories both of which were directed and manned by State of Arizona engineers and the deviations were confidential and not released.

## PART II "H" PLANT CALIBRATION AND EASE OF TRANSITION

The calibration of the McConnaughay Process Drum Mixer is the same as with the Shearer Process in Part I. The accuracy of gradation results from well controlled and constructed stockpiles.

## PART II "I" EFFECT ON ROLLING PROCEDURES

The tolerances required for temperature control to accomplish a uniform sequence of rolling procedures is the same as is presently used for conventional mixers to establish the proper or best sequence of rolling operations.

## PART II "J" RECOMMENDED CHANGES TO FAA STANDARDS

The recommended changes to the FAA Standard Specifications for Item P-401 Bituminous Surface Course are contained in Appendix C.

CONCLUSIONS AND RECOMMENDATIONS FOR  
THE SHEARER AND McCONNAUGHAY PROCESSES

CONCLUSIONS

The apparent enthusiasm of most highway paving engineers for the performance of the drum mixers should not be shared by airport engineers without a through study of local aggregates.

Airport asphaltic concrete pavements have characteristics which vary from highway mixtures in many ways. Some of them are critical and are listed below:

1. Airport runway pavements even on the busiest airports receive a rest period between each application of load while highway pavements have repeated load applications timed in the seconds which tends to keep the asphalt binder "live" and supplies a kneading action to the asphaltic concrete which increases the density of the mixture and decreases the voids.
2. Airport runways shut down for maintenance and repair are costly maneuvers, while shutdown lanes and detours are commonplace on highways even on newly constructed pavements.
3. Airport pavements at present receive load applications of nearly a million pounds with tire pressures exceeding 200 p.s.i. (14.06 Kg/cm<sup>2</sup>).

The airport engineer does not have the opportunity to correct a deteriorating pavement as readily as the highway engineer. His pavement design is for a minimal maintenance pavement with a life expectancy of 20 years for the heaviest aircraft anticipated to regularly use the airport.

The enthusiasm for the drum mixer is enhanced by its simplicity in design, fewer parts, portability, conformation to air quality requirements, low initial cost, and it appears to produce asphaltic mixtures of a quality equal to that of conventional plants.

Laboratory tests indicate that drum mixed pavements which have been placed two or three years have not shown abnormal deterioration in stability; no abnormal premature hardening of the asphalt and no abnormal stripping of the aggregate. However, the long term durability has not been proven, the expected pavement life has not been established and may cause excessive maintenance.

The initial cost savings may not be sufficient to cover the possible excessive maintenance costs, and in addition, the initial cost savings may not be as great as presently indicated if the specifications were based fairly for each type of mixer. Either the drum mixer should be penalized for moisture or the conventional stack up plant should receive an extra payment per ton for each percent of moisture below a set percentage. The cost of the asphalt cement per ton of airport mix is now approximately \$8.00 and the cost of aggregate mobilization, "demob", mixing, hauling and placing is about \$10.00 per ton, therefore five percent of moisture would be approximately \$1.00. Moisture contents of 3% to 5% are not uncommon. Early morning moisture has been seen as free running water from the bottom of the surge bins on some projects. Highly absorptive aggregates may contain higher moisture contents than the test results show as the absorbed water is given up only reluctantly. The moisture content may be as much as double the indicated percent moisture indicated in laboratory tests. Therefore on those projects where moisture content behind the paver was reported at 2% to 3% the actual

moisture content was probably 4% to 6% which is included in the cost.

It takes several years for absorptive aggregates to complete their absorption of asphalt cement. As the moisture leaves the aggregate the surrounding asphalt cement is absorbed into the aggregate and the total mixture is placed in tension with resultant cracking of the pavement. Highway pavements receive repetitive loadings with a kneading action to the pavement which tend to minimize the cracking.

The 28 mile Lakota test road in North Dakota (N.D. State Road #1) was completed in July 1972 using a Boeing drum mixer. After two years this test road showed an excessive number of transverse cracks. The crack count in 1975 was taken in two 1000 foot areas, one area showed 31 cracks and the other 61. These cracks projected to lane miles showed 164 cracks per lane mile and 222 cracks per lane mile.<sup>1</sup>

The writer inspected the Lakota test road in August 1976 and found that the road had received a seal coat treatment. Cracks showing through the seal coat had been hand sealed. It is not known when the cracks had been hand sealed, however some time must have elapsed at the time of the inspection since new cracks were showing in between the sealed cracks. A crack count beginning a mile north of Lakota to State Highway 17 a distance of 27 miles showed 8,172 cracks averaging over 302 cracks per lane mile. It may be noted that the same highway (N.D. State Road #1) north of Highway 17 was almost free of transverse cracks.

Excessive transverse cracks combined with the longitudinal cracking would be unacceptable for airport runways. The cold weather in North Dakota may be partially responsible for the excessive cracking reported for the Lakota Test Road.

<sup>1</sup>Association of Asphalt Paving Technologist, 1976

The Grand Canyon Airport Manager, in August 1976, ordered \$3000 worth of materials alone to seal the cracks in pavement placed in 1974. A Boeing Shearer process mixer was used on the job. The Kingman airport runway paved in 1975 shows extensive cracking. This pavement was also produced with a Boeing Shearer process mixer.

At Nome, Alaska the pavement has thermal cracking but otherwise it is in good condition. A Boeing Shearer mixer was also used on this project.

#### RECOMMENDATIONS

It is recommended that drum mixers be permitted for the manufacture of asphaltic concrete on Federal Aviation Administration Projects (ADAP) provided a non absorptive (1% or less) aggregate is specified.

When absorptive aggregates (over 1%) are permitted for use, drum mixers could be used for aprons and taxiways, however for runways the aggregate should be predried to a moisture content less than 0.5 percent.

In all cases with any type of mixing equipment provisions should be made to provide the contractor a bonus for dry mixtures or a penalty for excessive water in the mixture.

A wait and see attitude such as prevails with some engineers is not recommended, since the savings possible by use of this simple and effective type of mixer would be lost. It is recommended that each project be inspected periodically for a period of 10 years to ascertain if the design objectives are being obtained.



### PART III

#### RMI "THERMO-MATIC" SYSTEM

##### INTRODUCTION

This study of the RMI Thermo-Matic system includes two drums, one a prototype mixing plant (Thermo-Matic 100) with a capacity of 80 to 100 tons (73-91 Mg) per hour and a commercial model (Thermo-Matic 300) with a capacity of 250 to 300 tons (227-272 Mg) per hour.

The Thermo-Matic 100 was used for the construction of the jet blast area at the south end of Runway 1-R at McCarran International Airport, Las Vegas, Nevada. The Thermo-Matic 300 plant has been used on various city projects in Las Vegas and is now in operation on a Nevada State Highway project. It was planned to be used at the Kingman Arizona Airport as an alternate in the plans. The alternate was \$77,166.92 below the conventional plant bid. The \$77,166.92 is an indication of the cost savings that can be realized by using this plant.

The RMI Thermo-Matic 300 plant consists of a rotating drum into which have been placed 277 tubes, 3" (.076m) square and 16 tubes 2" x 3" (0.51-.076 m) running the length of the drum. The aggregate is fed into the drum on the opposite end from the burner. The flame and hot gases travel through the tubes heating the aggregate by conduction rather than by convection and radiation which occur in the drum mixers in Part I and Part II of this report. The mix is heated as it is passed counter-current to the hot gases. A fan for the exhaust gases creates a low negative pressure differential at the combustion chamber so that smoke emitted as the heated mix discharges from the heat exchanger is drawn into the fire box and burned. At no time does the mix come into direct contact with the hot gases from the burner.

### **PURPOSE**

The purpose of this study was to evaluate the suitability of bituminous mixes produced by the RMI Thermo-Matic system for use on airport pavement projects.

## SCOPE OF THE STUDY

The scope of the study included the following:

- A. The effectiveness of air quality control as to the amount and character of the stack emissions of the mixer at various projection rates.
- B. Correlation of the Marshall method design, using the temperature specified for the viscosity of the asphalt used with a modified Marshall procedure using the lower temperatures anticipated by the use of the RMI Thermo-Matic system.
- C. Evaluate the rolling techniques versus density requirements and the adequacy of the present special provisions concerning the minimum density requirements with the product of the drum mixer.
- D. Determine the effect of direct fire on bituminous mixtures heated to 240°F (116°C), 260°F (127°C), 280°F (138°C), and 300°F (149°C) measured by the rolling thin film oven test, versus rheological analysis of the extracted bituminous material mixed in the mixer.
- E. Determine the reliability of the RMI Thermo-Matic mixer equipment and ascertain if it can consistently produce a sufficient quantity of satisfactorily mixed asphaltic concrete to meet the production demands for heavy aircraft pavement designs, within a reasonable period of construction time.
- F. Determine the deviation from the mean of the "job mix formula" of the product from the RMI Thermo-Matic process.
- G. Determine the testing laboratory deviation of final test results performed by various laboratories and technicians.
- H. Determine the methods and accuracy of the calibration of the plant together with a study of the ease of transition for the paving plant operator from standard stackup plants to the RMI Thermo-Matic mixer.
- I. Determine the tolerances required for temperature control to accomplish a uniform sequence of rolling procedures.
- J. Recommended changes to FAA standards.

### PART III "A" ENVIRONMENTAL EFFECT OF THE RMI THERMO-MATIC PLANT

The RMI Thermo-Matic plant design incorporates an internal structure that prevents any of the burners' gaseous combustion products from coming into direct contact with the hot asphaltic concrete. Any vapors which may be formed in the hot mix during mixing are routed back through the combustion chamber, thus insuring that even gaseous hydrocarbons evolved during heating and mixing will not escape to the atmosphere unburned. The exhaust from the heat exchanger is clear and passes the stringent requirements of the Los Angeles Air Pollution Control District.

### PART III "B" CORRELATION OF THE MARSHALL DESIGN

The method of heat exchange permits the same mixing temperatures as specified in the FAA specifications previously written for standard asphalt plants; therefore, temperature revisions are not necessary with the RMI plant.

The FAA specifications for P-401 Bituminous Surface Course and the Marshall mix design procedures for new asphaltic concrete do not need any changes. For recycling old asphaltic concrete they need only slight changes to permit the use of this equipment. The ASTM D-1559 method for Marshall design does not need changes. However, in calculating the voids and voids filled, the specific gravity of the aggregates and the viscosity of the asphalt cement the technician must first determine the viscosity of the asphalt cement, in the old asphaltic concrete, the amount of softening agent required to reach the specified viscosity of the grade of asphalt specified, and the specific gravity of the aggregates in the old asphaltic concrete (see Appendix D for mix design procedure).

The RMI Thermo-Matic plant was not developed as a drum mixer such as the Shearer parallel flow process or the McConnaughay turbulent mass process but more for mixing of crushed old and oxidized asphaltic concrete. The RMI process is a method of producing asphaltic concrete hot mix, which, when used in lieu of conventional methods can save the equivalent of over 15 gallons of fuel oil per ton of asphaltic concrete. This fuel saving is made possible by using an additive to the crushed old asphaltic concrete resulting in a product virtually indistinguishable from new asphaltic concrete according to test results available from Robert L. Dunning.

It may be noted that 1,000 tons (900 Mg) of airfield pavement contain approximately 16,000 to 17,000 gallons (60,560 - 64,345 l) of asphalt and about 930 to 940 tons (842-852 Mg) of crushed and processed aggregate . In general, the cost of tearing up and hauling old pavement to a dump and burying it is a significant figure; however, this old pavement may be crushed near the construction site and recycled at a great savings in cost and conservation of imported natural resources. There are large quantities of discarded asphalt concrete pavement in the United States each year. Properly stockpiled this waste material would be a valuable resource for future use.

In the RMI process the crushed old pavement is screened in the same manner as virgin aggregate and placed in stockpiles. New materials are also stockpiled to permit adjustments in the gradation the same as is done for the other drum mixers. Sensing devices at the downstream end of the drum automatically determine and control the correct feed proportions of the crushed old pavement, new aggregate, and liquid asphalt necessary to meet the asphaltic concrete specifications. A softening agent is used to increase the penetration of the old asphalt to meet the grade of asphalt specified.

The savings in costs over new asphaltic concrete is estimated at \$2.60 per ton.

#### PART III "C" EFFECT OF THERMO-MATIC MIXING ON DENSITY

The results of the field tests of the P-401 surface course material at McCarron International Airport showed an overall average of 98.3% of Marshall maximum density was obtained.

#### PART III "D" EFFECT OF DIRECT FIRE ON BITUMINOUS MIXTURES

This portion is not applicable to the Thermo-Matic plant as the bituminous mixture is never in contact with a direct flame. The heating is accomplished by a heat exchanger. (see A above)

#### PART III "E" QUANTITATIVE RELIABILITY OF THE RMI THERMO-MATIC MIXER

The ability of the RMI Thermo-Matic mixer to produce a sufficient quantity of satisfactorily mixed asphalt concrete meeting the demands of the airport design engineers has been proven on small jobs. To date there has been very little time lost due to break downs. The commercial model has performed without any down time, however, the maximum production of the Thermo-Matic 300 is only 300 tons per hour. Higher production drums may be manufactured in the near future.

### PART III "F" QUALITATIVE ANALYSIS OF THE MIXTURE

The test results of the McCarron International Airport project indicate the quality of the asphaltic concrete produced fully met the Federal Aviation Administration specifications for P-401 bituminous surfacing.

### PART III "G" LABORATORY DEVIATION TEST RESULTS

There was no opportunity to check the laboratory deviation on the McCarron Airport Project, however the test results reported in Part I are applicable to this portion of the study.

### PART III "H" PLANT CALIBRATION AND EASE OF TRANSITION

The calibration of the RMI Thermo-Matic mixer is the same as the mixers in Part I and Part II. The same system of cold aggregate feed is used with all three mixers studied.

### PART III "I" EFFECT ON ROLLING PROCEDURES

The tolerances required for mix temperature control to accomplish a uniform sequence of rolling procedures are identical to standard stackup plants as direct fire never comes in contact with the hot bituminous mixture.

### PART III "J" RECOMMENDED CHANGES IN SPECIFICATION

The recommendations for changes to the FAA specifications for Item P-401 Bituminous Surface Course are contained in Appendix "C".

## CONCLUSIONS AND RECOMMENDATIONS FOR RMI THERMO-MATIC MIXERS

### CONCLUSIONS

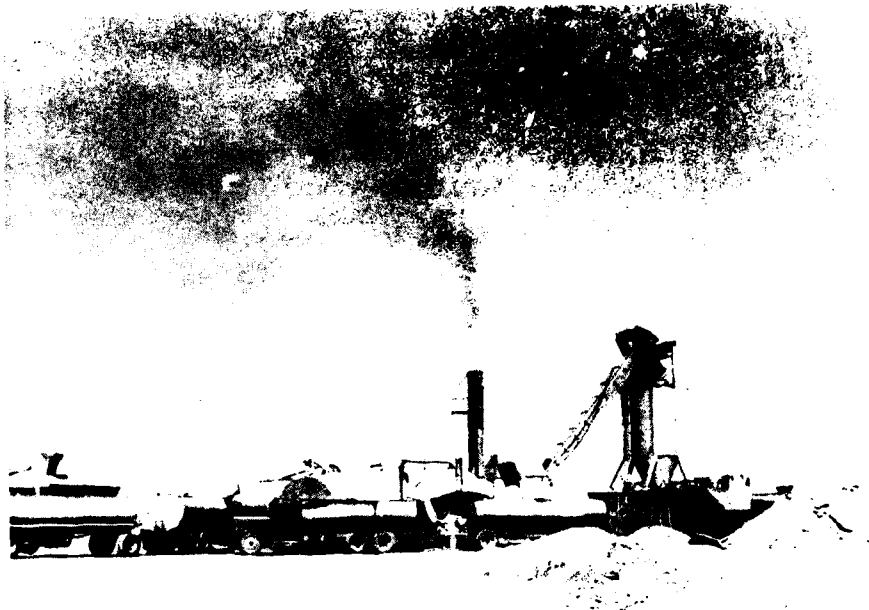
The RMI Thermo-Matic mixing plant should be accepted by FAA for use on airport construction. The potential of this plant for producing high quality asphaltic concrete should be considered as an alternative to both drum mix plants and conventional stackup plants for the following reasons:

1. The cost of removal and disposal of old asphaltic concrete on airport projects has been a large part of construction, it can now be recycled into the new work at a large savings in money, time and energy.
2. The aggregate in old asphaltic concrete has probably absorbed all the asphalt it can absorb. The mixture using these aggregates will contain less water and less voids resulting in a bituminous mixture that will have a high adhesion and a low crack potential, and yet save fuel oil, asphalt cement and aggregate.

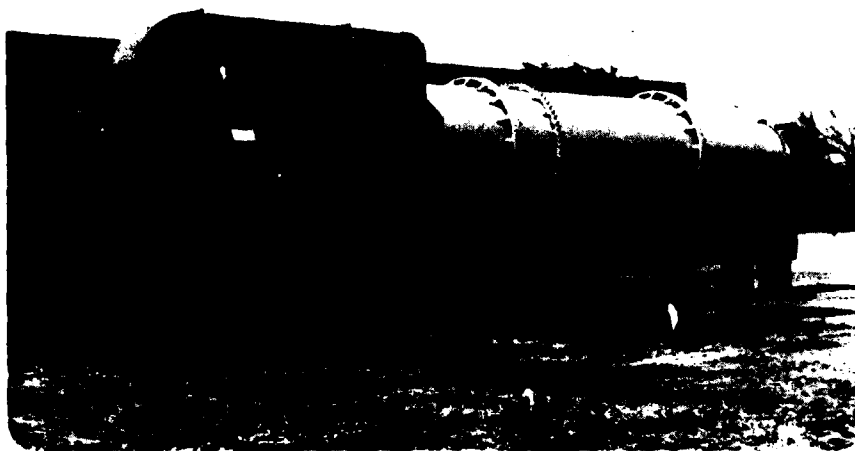
### RECOMMENDATIONS

All FAA Specifications for future work should provide an alternate for use of recycled asphaltic concrete.





Photograph E. Cedarapids turbulent mass mixer.



Photograph F. CMI turbulent mass mixer.

REPORT ON THE DRYER-DRUM PROCESS  
NOME AIRPORT RECONSTRUCTION PROJECT  
NOME, ALASKA  
MARCH 25, 1976

In 1971, the State of Alaska, Division of Aviation awarded a contract for various improvements at Nome Airport which was federally funded under the Airport Development Aid Program (ADAP). The work description for this project included: reconstruction of the E/W runway, taxiways and apron; installation of high intensity runway lights and medium intensity taxiway lights; and pavement marking. The contract was awarded to the low bidder in the amount of \$2,428,822.

The contract called for the placement of 35,565 tons of bituminous concrete utilizing 120/150 penetration paving grade asphaltic cement. The typical pavement sections specified a 2-inch thickness on shoulder area and a 3-inch thickness in structural pavement areas to be placed in two 1-1/2-inch lifts. The use of a conventional batch or continuous mixing plant was also specified.

Prior to commencing paving operations, the contractor requested permission to use the dryer-drum process in lieu of the specified conventional batch or continuous plant methods. This request was approved by the sponsor and FAA, and the specifications were modified by supplemental agreement (copy attached) to permit the use of the dryer-drum process. The contract unit prices remained unchanged at \$11.50/ton asphalt surfacing in place and \$160/ton 120/150 asphaltic cement.

The asphalt plant was purchased new from the Boeing Company and shipped by barge from Seattle to Nome. The plant was equipped for remote operation and all phases of the mixing process were constantly monitored and adjustments made at a central control panel. The cold feed bins were fed from two stockpiles - coarse pile 3/4" to 3/8" and fine pile 3/8" minus. Moisture content of the cold feed aggregate averaged about 3 percent.

When the bugs were worked out of the new plant, there was no particular problem holding the mix within job-mix tolerances, except for a constant problem with excessive minus 200 material. This particular problem was anticipated prior to the actual work based on past experience with the borrow source which was composed of schist type rock. The 200 material ran from about 1 to 1-1/2 percent above the 6 percent upper limit.

Actual paving started in July 1973. During the initial startup the mix was discharged from the plant at a temperature of from 250° to 270°F. Initial breakdown rolling was accomplished with a steel-tandem roller, followed by a multi-wheel rubber-tired roller, then a final rolling with a second steel-tandem roller. The pavement remained somewhat pliable down to a temperature of 150°F, but it was doubtful that any increase in densification was realized below 200°F. The completed pavement looked excellent from the standpoint of surface texture and also surface smoothness. Stabilities were in excess of

1600 and densities averaged 96 percent of Marshall (75 blows). Specification called for 1800 stability and 98 percent of Marshall. The moisture content of the mix placed on grade was less than 0.5 percent.

A paving consultant representing the dryer-drum manufacturer visited the project and stated that mixing at temperatures of 250° to 270°F was defeating the purpose of the dryer-drum process because it drives off moisture which is required to place and compact the mix at low temperatures. He said that the mix should be discharged from the plant at 210°F, in order to ensure adequate moisture retention - hopefully around 2 percent - which should, in turn, facilitate densification of the paving mix. It was therefore agreed to place a 100-ton test strip of the low temperature mix.

The low temperature mix was discharged from the plant at from 180° to 210°F., and placed on grade at an average temperature of 195°. The test strip was rolled with a steel-tandem breakdown roller, then a rubber-tired roller, and finally a second steel-tandem roller. The following observations were noted regarding the quality of the completed test strip: (1) Aggregate on the low temperature mix was improperly coated, which would result in excessive deterioration from freeze-thaw, (2) excessive pickup was evident on the surface of the mat in the form of small blobs which had been rerolled into the surface, which would pop-out during the first winter. And (3) there was no apparent benefits to be gained by going to the lower mixing temperature. It was later learned that stabilities on the low temperature mix ranged from 700 to 800, which pretty much discouraged any further consideration of this particular mixing procedure.

The manufacturer's representative also suggested that laboratory specimens for determining field compaction should be pounded out at on grade rolling temperatures rather than reheating to the standard Marshall temperature of 250°F. This, of course, would lower the standard and thereby increase the percent compaction. We had no objection to this procedure if used for informational purposes only; however, the actual job control would have to be based on standard Marshall as specified in the contract. By using the standard Marshall, we would obtain test results that could be readily correlated with test data from previous paving projects, and thereby come up with a more realistic evaluation of the new Shearer (dryer-drum) process for mixing asphaltic concrete compared to standard mixing methods.

#### Conclusions:

1. More care must be taken in stockpiling aggregates for the dryer-drum process since the aggregate is blended and charged directly into the drum from the stockpiles. If the stockpiles are properly prepared, the mix can be held within job-tolerances.
2. The asphalt content can be held within job-mix tolerances if the cold feed is equipped with a constant moisture readout so that timely adjustments in the aggregate cold feed can be accomplished to compensate for variations in moisture content.

3. It is doubtful from our experience that placement of low temperature mixes, as advertised by manufacturers, can produce a pavement meeting the high stability and compaction requirements for airfields. We feel that the higher mixing temperature used at Nome produced a superior product.
4. We are well pleased with the quality of pavement produced by the dryer-drum process at Nome. The pavement surfaces have excellent surface texture and surface smoothness after two years of age.
5. There is a critical need to develop a standard procedure for testing mixes produced by the dryer-drum process - i.e., compaction standard and stability determination.

ROBERT L. DUNNING

*Petroleum Sciences*

Asphalt Technology • Asphalt Emulsions • Polymer Asphalts • Rheology

EVALUATION OF DRUM MIXED  
ASPHALT CONCRETE AT VARIOUS MIXING  
TEMPERATURES

Robert L. Dunning

Project 1014

Client: Ernest Rosholt

October 1974

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## INTRODUCTION

Ernest Rosholt, a consulting engineer in asphalt technology, submitted four samples of asphalt concrete which were obtained during a field test of a drum mixer. These samples represented asphalt concrete mixed at 240°, 260°, 280° and 300° F. The scope of this project was to determine the change in the rheological properties of the asphalt extracted from each of those samples, and to compare those properties with the properties of the original asphalt before and after hardening in the RTF-C. The location of the test project was at the Grand Canyon Airport in Arizona.

## EXPERIMENTAL

The four samples were extracted by ASTM D-2172 and recovered by the Abson method, ASTM D-1856. On those samples, the penetration at 77° F (ASTM D-5), and viscosities at 140° F and 275° F (ASTM D-2171 and D-2170 respectively) were determined. The penetration and viscosities of the original asphalt was also determined before and after the RTF-C test, (California Test Method 346).

## RESULTS AND DISCUSSION

As may be seen in the Table, the asphalts did not harden as much in the drum mixer as did that same asphalt in the RTFC test. This would suggest that less oxidation occurs in drum mixers than in a pugmill, since the RTFC test is supposed to approximate the average oxidation of an asphalt while being mixed in the pugmill. In the absence of a direct comparison with a pugmill mixed batch using the same aggregate, this conclusion should be used advisedly since aggregates can have a catalytic effect on asphalt to a varying degree, and the oxidation in the RTFC represents the average oxidation one would expect, not what one would always get irrespective of the aggregate used.

Haas<sup>1)</sup> has shown that the recovered asphalt from a drum mixing operation gets softer as the temperature is increased, which is just the opposite of that which is observed in pugmill mixing. The data presented here are in general agreement with those of Haas.

The rate of change in the viscosity at 275° F with respect to the viscosity at 140° F provides some interesting information. See the figure. In mixes prepared at 240° F and 260° F, that rate was greater than that found during the RTF-C test, indicating oxidation is taking place. In air blowing of asphalt, a catalyst would be needed to make the 275° F viscosity increase more rapidly than that which occurs<sup>2)</sup> in the RTF-C test, which is essentially an air blowing operation. The oxidation of asphalt probably has at least two mechanisms. One mechanism is chain scission, in which the carbon-carbon bonds break, resulting in a softening of the asphalt.

The other reaction is a condensation reaction, in which large molecules are formed, resulting in a hardening of an asphalt. At lower temperatures, the chain scission mechanism may be replaced by partial oxidation (addition of carbonyl groups) without complete scission. That would harden rather than soften an asphalt. This would be an alternate explanation to catalytic oxidation for the high 275°F viscosities. At 280° and 300°F, on the other hand, the rate of change in the 275°F viscosity with respect to the 140°F viscosity is more like that which would occur if the asphalt was distilled to a harder grade. The obvious explanation is that at 280 degrees and higher, the burner depletes the oxygen supply, leaving only the stripping action of the burner gases and steam from the wet aggregate.

#### CONCLUSIONS

1. As the mixing temperature of the drum mixer is increased, with other factors held constant, the rate of hardening of the asphalt is decreased.

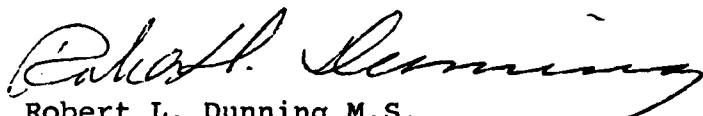
2. At 240° and 260°F, the viscosity at 275°F increases at a rate faster than would be expected by strict air oxidation, as indicated by the RTF-C test.

3. At 280° and 300°F, the viscosity increase at 275°F resembled that which would be obtained by distillation rather than that which would be expected by oxidation. This may be explained by oxygen depletion from the burner and stripping by the water and combustion gases.

4. If mixing is to be accomplished at 300°F, it may be well to specify an asphalt one grade harder than that specified for pug-mill mixing.

#### BIBLIOGRAPHY

- 1) Stanley Haas, Proc. AAPT. 43 (1974) to be published.
- 2) R.L. Dunning and J.L. Meeks. Proc. AAPT 37 529 (1965).



Robert L. Dunning M.S.  
Consulting Chemist

Effect of Mix Temperature of

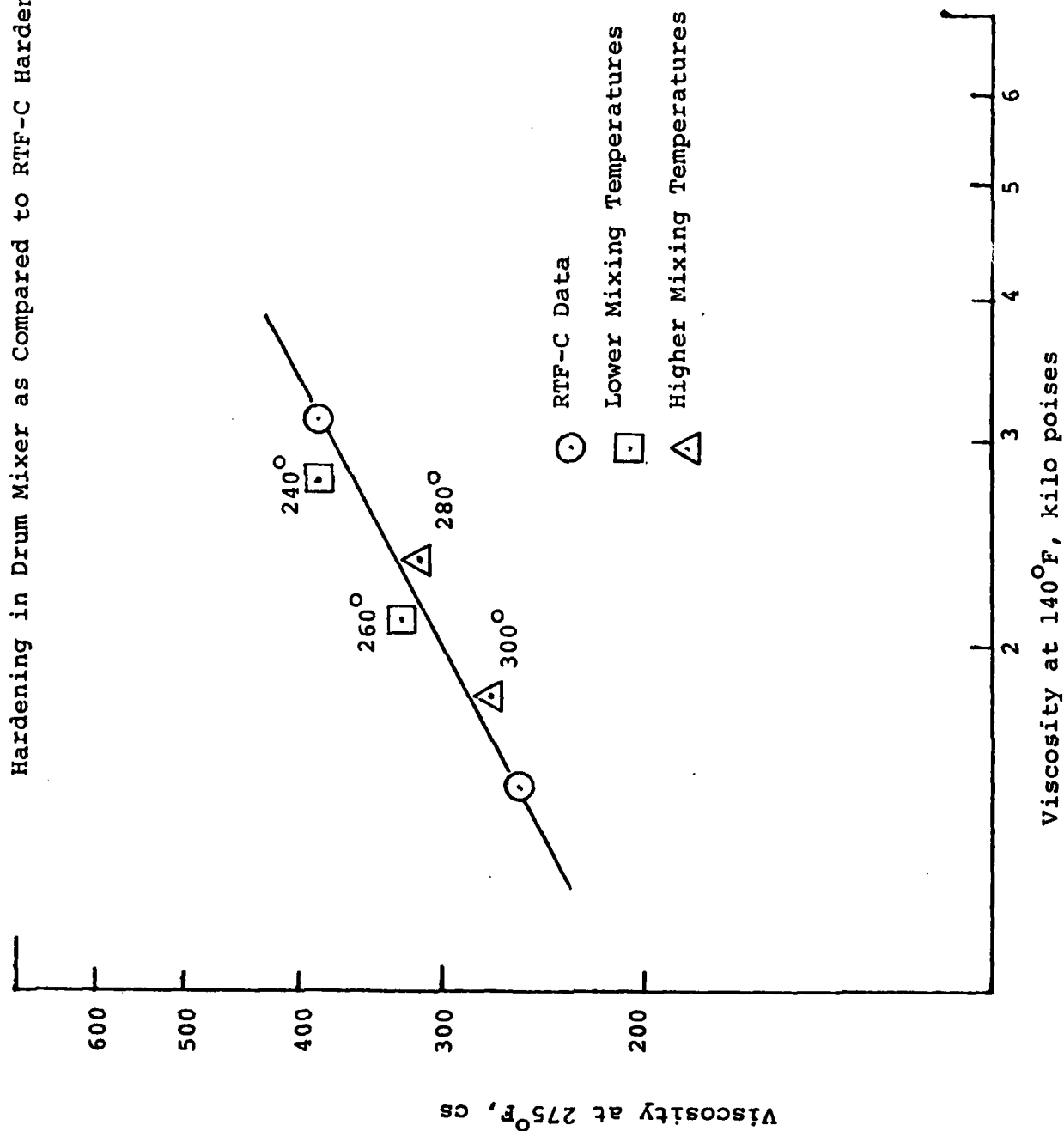
Rheological Properties of

Drum Mixed Asphalt Concrete

	Pen @ 77°F dmm	Viscosity	
		140°F, poises	275°F, cs
<u>Asphalt</u>			
On Original Asphalt	64	1500	260
After RFTC	42	3110	383
<u>Extracted from Mixes</u>			
Mixed at 240°F	50	2770	383
Mixed at 260°F	57	2100	327
Mixed at 280°F	50	2380	318
Mixed at 300°F	60	1810	273



# Hardening in Drum Mixer as Compared to RTF-C Hardening



RECOMMENDED CHANGES TO ITEM P-401

BITUMINOUS SURFACE COURSE

401-2.3 BITUMINOUS MATERIAL - Add to this section;

**NOTE:** The Western States do not use penetration grades. In those states that do not have penetration grades, aged residue grades will be acceptable. The AR grades are determined by viscosity. They are AR-2000, AR-4000, AR-8000 and AR-16000. In cold climates the AR-2000 should be specified while in hot arid climates higher grades should be used. If drum mixers are to be used the mixing temperature should be lowered to 240° - 260°F.

401-3.1 COMPOSITION OF MIXTURES - In table for ASTM D-1560 change "percent voids" from (Min) 4; to 3 to 5

401-4.2 BITUMINOUS MIXING PLANT

(a) (1) Plant scales - Add final sentence; When drum mixers are used by the contractor, belt scales may be approved for plant calibration and mix proportions.

(a) (3) Feeder for drier - Change to; Feeder for drum or drier. The plant shall be provided with accurate mechanical means for uniformly feeding the aggregate into the drier or drum to obtain uniform production and temperature.

(a) (4) Add to end of sentence; except when drum mixers are used.

(a) (5) Add to end of sentence; except when drum mixers are used.

(a) (8) Change second sentence to read; The plant shall also be equipped with an approved thermometric instrument placed at the discharge chute of the drum or drier to indicate the temperature of the heated aggregates.

(a) (9) Add to end of sentence; except when drum mixers are used.

(c) Change heading to read; Requirements for Continuous Mix Plants Including Drum Mixers.

(c) (1) Add to end of second paragraph; except in plants which provide electronic controls operated from a central control room. The JMF dial settings shall be locked after calibration.

(c) (2) Add to end of paragraph; Belt scales are considered satisfactory provided check weights show that the required accuracy is being obtained.

(c) (4) Change heading to read; Pugmill Mixer

add (c) (5) Drum Mixer - The drum mixing plant shall be an approved continuous mixer adequately heated and capable of producing a uniform mixture within the job mix tolerances.

401-4.6 PREPARATION OF MINERAL AGGREGATE - Add to end of paragraph;  
When drum mixers are used the combined aggregate shall contain not more  
than 3% moisture when discharged from the drum mixer.

401-4.8 TRANSPORTATION AND DELIVERY OF THE MIXTURE - Change second  
sentence to read; The mixture shall be placed at a temperature between  
200° and 250° when drum mixers are used; 150° and 225°F when tar is used;  
and between 250° and 300°F when asphalt cement is used with standard plants.

401-4.10 COMPACTION OF MIXTURE - Add new paragraph at end of section;  
The first lane of pavement may be used to establish the best rolling  
sequence for the rolling equipment being supplied by the contractor.  
Nuclear readings should be taken after each pass while varying the type of  
roller. Curves should be plotted on pounds per cubic feet. The sequence  
giving the highest density without over rolling should be used.

APPENDIX D  
MIX DESIGN PROCEDURE  
FOR  
RECYCLED ASPHALT PAVEMENTS  
MARSHALL METHOD

- I. Determination of Softening Agent Required
  - A. Extract a sample of pavement to be recycled and recover the asphalt by the Abson Method (ASTM D-1856). Determine the asphalt content of the mix.
  - B. Divide the recovered asphalt into four samples. Add 0, 5%, 10%, and 20% of softening agent to those samples and determine the viscosity at 140°F of each sample.
  - C. Plot viscosity at 140°F vs % of softening agent (paxole or equal) on semilog graph paper and calculate the amounts required to obtain viscosities of 3000, 4000, and 5000 poises.
  - D. Calculate amount of asphalt cement required, based on total mix, by multiplying the amounts calculated in "C" above by the % asphalt determined in "A" above and divide by 100.
  - E. Report the amount of softening agent, based upon total mix required to obtain asphalt viscosities to 3000, 4000, and 5000 poises.
- II. Gradation and Asphalt Content Adjustment
  - A. Obtain samples of each of the stock piles (new and recycled material).
  - B. Determine % asphalt and gradation of each.
  - C. Calculate the bin ratios required to meet specifications.
  - D. Using the bin ratios calculated in "II-C", calculate the asphalt content in the combined mix.
  - E. Report stockpile gradations and asphalt contents, bin ratios, and the combined gradation and asphalt content.
- III. Mix Design
  - A. Prepare four samples of three Marshall specimens each with the following composition:
    1. Combined gradation of new and recycled pavement as reported in "II-E".
    2. Sufficient softening agent to obtain an asphalt viscosity of 400 poises.

3. The following amounts of specified grade asphalt to the samples, based upon total mix.

- a) Sample #1. 0%.
- b) Sample #2. 0.5%.
- c) Sample #3. 1.0%.
- d) Sample #4. 1.5%.

- B. Coat the specimens with zinc stearate and determine specific gravity. Measure height of each specimen.
- C. Determine Marshall stability and flow.
- D. Combine the three specimens of each sample and dry in an oven.
- E. Determine the Rice Specific Gravity of each sample.
- F. Calculate % voids, % voids filled, and select optimum mix in the normal manner. Use the Rice Specific Gravity as the Theoretical maximum specific gravity.

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-80